SECTION 5 - RESULTS OF OTHER INVESTIGATIONS

5.1 Impact Within The Dredged Area

The increased exploitation of marine deposits and the physical impact of dredging works has been widely reviewed (*see* Shelton & Rolfe, 1972; Dickson & Lee 1973; Cruikshank & Hess, 1975; Eden, 1975; Millner *et al*, 1977; de Groot, 1979b; van der Veer *et al*, 1985; Glasby, 1986; Gajewski & Uscinowicz, 1993; ICES, 1993; Land *et al*, 1994; Whiteside *et al*, 1995; Hitchcock & Dearnaley, 1995; Hitchcock & Drucker, 1996; Hitchcock, 1997).

Dickson & Lee (1973) studied the recovery of test pits dug by anchor dredge in gravel deposits of the Shingle Bank, Hastings, off the south east coast of England. They found that the pits were very slow to fill and were still visible after two years. In another study, van der Veer *et al* (1985) described the recovery of pits in sandy substrates in the Dutch Wadden Sea. They showed that in this instance pits in channels with a high current velocity filled within one year, but those in the lower current velocities which occur in tidal watersheds took 5-10 years to fill whilst those in tidal flat areas were still visible after 15 years. In contrast, dredge furrows in the Bristol Channel have been observed to disappear within 2-3 tidal cycles or less, due to high sediment mobility.

Because the deposits required for marine aggregate are coarse, and sediment disturbance by wave action in any case limited mainly to depths of less than 30 metres even during storm conditions, it follows that not only is the fauna likely to be removed in patches from the dredged areas, but pits and furrows are likely to be persistent features of the sea bed topography for several years except in areas where the sands are mobile.

Such sediment movement as does occur is mainly through slumping of the sides of the pits and subsequent infilling by fine particulates transported by tidal currents into the pits which reduce current velocity and act as sediment traps. This can lead to heavily anoxic sediments and to colonisation by a community which differs considerably from that in the original deposits (Shelton & Rolfe, 1972; Dickson & Lee, 1973; Kaplan *et al*, 1975; Bonsdorff, 1983; Hily, 1983; van der Veer *et al*, 1985; Hall, 1994).

Side-scan sonar records in coastal waters of the southern North Sea show that the sea bed is crossed by a series of dredge tracks which are 2-3 metres wide and up to 50 cm deep (van Moorsel & Waardenberg, 1990a & b; Kenny & Rees, 1994) although deeper troughs of up to 2 metres were recorded from areas where the dredge head had crossed the area several times.

Davies & Hitchcock (1992) studied high resolution sidescan sonar profiles of a large number of dredge cuts produced by different dredge vessels operating on different U.K. Licence Areas. They found that the average cut depth ranged from 0.34m-0.55m and cut width from 2.5m-3.7m depending on the type of draghead and substrate. Somewhat deeper troughs of up to 70 cm were reported for the Baltic (Gajewski & Uscinowicz, 1993).

In this case removal of the surface 0.5 metres of deposit would be sufficient to eliminate the benthos from the deposits in strips, the total removal depending on the intensity of dredging at a particular worked site.

Despite the shallower depth of removal, the evidence suggests that infilling of the troughs from trailer suction dredging takes at least 12 months in the Baltic and is achieved partly by slumping from the sides and partly by transport of fine material by bottom currents into the sediment traps formed by the dredged furrows (Kaplan *et al*, 1975; Hily, 1983; van der Veer *et al*, 1985; Gajewski & Uscinowicz, 1993). Progressive removal of the original sandy gravel and its replacement by fine sand has also been reported for the sediments off Dieppe by Desprez (1992). In the case of experimental furrows dredged by trailer suction in gravel deposits of the southern North Sea off the Suffolk coast of England, even shallow depressions of only 20-30 cm depth were still visible on side-scan sonar records made up to four years later (Millner *et al*, 1977).

Rather unexpectedly, Kenny & Rees (1994, 1996) found an increase in the particle size of deposits in the dredged areas, possibly reflecting the exposure of coarse deposits at depth below the surface gravel layers. In this study which was carried out in the southern North Sea, the dredged furrows were visible with side scan sonar even after 2 years. Similar results have been reported for dredging tracks off the French coast at Dieppe (Desprez, 1992), although winter storms obliterated tracks within a few months on the Klaverbank in the Dutch sector of the North Sea (Sips and Waardenberg, 1989; Van Moorsel & Waardenberg, 1990, 1991). In general, dredge tracks will persist for varying times depending on the rate of local sediment fluxes. Recent measurements suggest this may be as short as only a few days in high energy environs such as the Bristol Channel and Norfolk Banks, but periods as long as several years for more stable deposits along the south coast of the U.K. (A. R Hermiston, 1998, *pers.comm.)*

Both anchor dredging and trailer suction dredging thus both have an important potential impact on the biology of the dredged areas, since no benthos is likely to occur below the dredged depth. This can be expected to lead to a patchy distribution of organisms, reflecting the differences between the dredged furrows and the intervening undredged surfaces. Such recolonisation as occurs within the dredged areas is likely to be by migration of adults through transport on tidal currents (Rees *et al* 1976; Hall, 1994); by transport in sediments slumping from the sides of the pits and furrows (McCall, 1976; Guillou & Hily, 1983); by the return of some undamaged components through outwash from the chutes and spillways (*see* Lees *et al*, 1992; MAFF, 1993); and by colonisation and subsequent growth of larvae from neighbouring populations. In this case, a clear succession of colonising species is to be anticipated, leading to the establishment of definite clusters, or patches in benthic community composition depending on the type of deposits which have infilled the dredged areas and the time since the recolonisation sequence started.

Author	**Date**	**Distance**	**Water Depth**	**Current Velocity**	**Particle Sizes**
Åker, Häkkinen & Winterhalter	1990[*]	200-300m			
Davies	1984[*]	< 500m	N/A	N/A	silts, clays
HR Wallingford	1994[#]	< 11000m	25m	1.75m/s	very fine sands
		< 5000m			fine sands
		< 1000m			medium sand
		< 50m			coarse sand
HR Wallingford	1993[#]	< 6500m	25m	0.9m/s	very fine sands
Pennekamp *et al*	1996	<1.5hrs	N/A	low	clays/silts
Gajewski & Uscinowicz	1993	<300m	8-25m	low	sands
Kioerboe & Moehlenberg	1981	<1000m	N/A	N/A	background
Poopetch	1982	<800m	N/A	N/A	background

Table 5.1 *Summary table of results of similar dredging plume study investigations. Note however that these are largely concerned with the behaviour of fine silts and clays, rather than sediments associated with aggregate mining.*

5.2 Impact Adjacent To The Dredged Area

Although a good deal of concern has been expressed about the possible impact of marine aggregate extraction on coastal resources (*see* ICES, 1992a, b), the possible scale of impact outside the immediate dredged area from the settlement on the seabed of fine material temporarily suspended by marine aggregate dredging is poorly understood.

It has often been assumed for the purposes of simulation models for British coastal waters that the dispersion of material rejected *via* the reject chute and spillways during the dredging process is controlled by Gaussian diffusion principles and that suspended material could be carried by tidal currents for as much as 20-km on each side of a point source of discharge.

Indeed, in water depths up to 25m and peak spring tide velocities of 1.75m/s, very fine sand may travel up to 11km from the dredging site, fine sand up to 5km, medium sand up to 1km and coarse sand less than 50m (HR Wallingford, 1994). In current regimes with a lower peak velocity of some 0.9m/s, similar sized material may only travel up to 6.5km from the point of release (HR Wallingford, 1993). Worst case estimates have suggested that sediment plumes may persist for up to 4-5 tidal cycles (HR Wallingford, 1994).

Interestingly, detailed and extensive monitoring campaigns associated with the construction of the Størebælt Link have detected suspended sediment related to a specific dredging operation up to 35km from the source. However simulations have shown that 6km from the operations, the monthly average surplus SSC caused by some of the most intensive dredging operations were at the same level as the background concentration (2 mg/l).

More recently, Acoustic Doppler Current Profiling (ADCP) techniques have been used to determine plume dispersion in relation to spoils dispersal from both commercial aggregate dredgers (Hitchcock & Drucker, 1996) and in relation to capital dredging works and sand mining (Land *et al*, 1994; Whiteside *et al* 1995). Remote airborne and satellite imagery has also proved to be a useful tool in defining the contours of sediment dispersal (Whiteside *et al* 1995).

As referred elsewhere within this Report, recent studies made on the dispersion of sediment plumes generated from dredging operations suggest, however, that the area of impact of outwash from dredging activities is smaller than results of modelling based on Gaussian diffusion principles imply, especially where the proportion of silt and clay in the deposits is low.

A comprehensive study has been undertaken in the Baltic Sea (Gajewski & Uscinowicz, 1993). Observing plume formation from trial trailer dredging operations, they found that the majority of sediment from the plume fell into traps placed near the seabed within 50m of the dredge track. At distances greater than 50-metres the amount of material settling on the seafloor decreased rapidly (Figure 5.2a). Current movements were low. Settling rates at 50m were less than 1200g/m^2. Settlement within the dredge furrow was estimated at 5-10mm, which has been correlated with a settlement rate of ca. 7500-15000g/m^2.

Importantly, Gajewski and Uscinowicz conclude that the disturbance of the light extinction field, i.e. the SPM field caused by dredging is only significant adjacent to the operation (up to 50m). Further, any geomorphologic impact caused by the sediment plume is localised and short lived.

Åker, Häkkinen & Winterhalter (1990) report that turbid waters could not be detected further than 'a few hundred meters' downcurrent from the dredger. Normal water quality variations caused by current activity and storm suspension were found to be greater than that caused by sand extraction. They also consider that the operation had no clearly detectable effect on fishing in the general area.

Van der Veer (1979, *In:* van der Veer *et al*, 1985) measured overflow concentrations of suspended sediment from a small dredger to be 6300 mg/l, within range of the results obtained here. Background concentrations were found to average 60 mg/l.

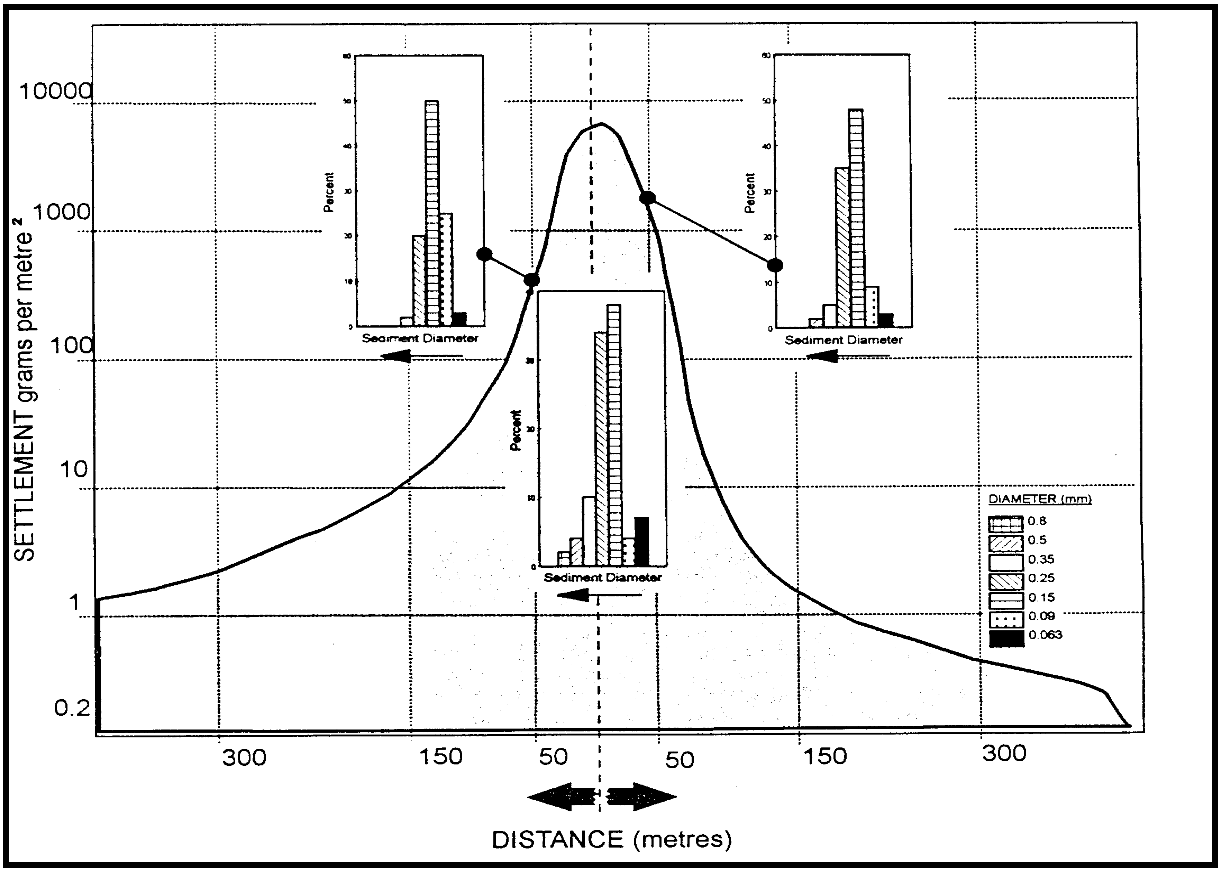

Figure 5.2a *Diagram showing the settlement of overflow sediments during dredging operations from trailer dredging in the Baltic. Particle size profiles for the sediments deposited in the track of the dredger and 50-metres on each side of the dredger are also shown. Note that the main deposition of sediment was confined to distances within 150m on each side of the dredger track (after Gajewski & Uscinowicz, 1993)*

The recent study by Whiteside *et al* (1995; *see also* Johanson & Boehmer, 1975; Gayman, 1978) has shown that the behaviour of plumes discharged during sand dredging can best be regarded as comprising an initial "Dynamic Phase" during which the sediment-water mixture descends rapidly to the seabed as a density current jet at a rate which depends on the overflow density, the diameter of the discharge pipe, the water depth, the velocity of discharge and the speed of the dredger.

During its passage through the water column and following impact with the seabed the sediment is dispersed into the water and forms a well-defined plume astern of the dredger. This second longer phase has been referred to as the "Passive Phase" of dispersion by Whiteside *et al* (1995) and starts approximately 10 minutes after outflow. During this phase the material behaves in a relatively simple settling mode according to Stokes Law, the plume then decaying to background levels after a period of 2-3 hours.

Their study showed that approximately 100 metres (corresponding to approximately 3 minutes from the overflow) astern of a dredger working in Hong Kong waters the plume surface sediment concentrations were from 75-150 mg/litre. Levels were halved in 10 minutes and reduced to 20-30 mg/litre after 30 minutes. This approached the recorded background suspended solids concentration of 10-15 mg/litre and indicated that only a relatively small proportion of the fines category (<63-mm) remained in the water column at the start of the passive phase of dispersion ten minutes after discharge. Even then, their data suggest that the settlement rate of the plume continued to be more rapid than simple particle settlement would suggest.

A plume dispersion model developed by Whiteside *et al* (1995) for the surface layer (the upper 8-metres of the water column) for up to 40-minutes after discharge is shown in Figure 5.2b and compares well with plume decay measurements in the vicinity of the dredger. The contours for sediment deposition evidently remain as a narrow band extending for approximately 100-metres on each side of the track of the dredging vessel, much as recorded by Gajewski & Uscinowicz (1993) for Baltic waters.

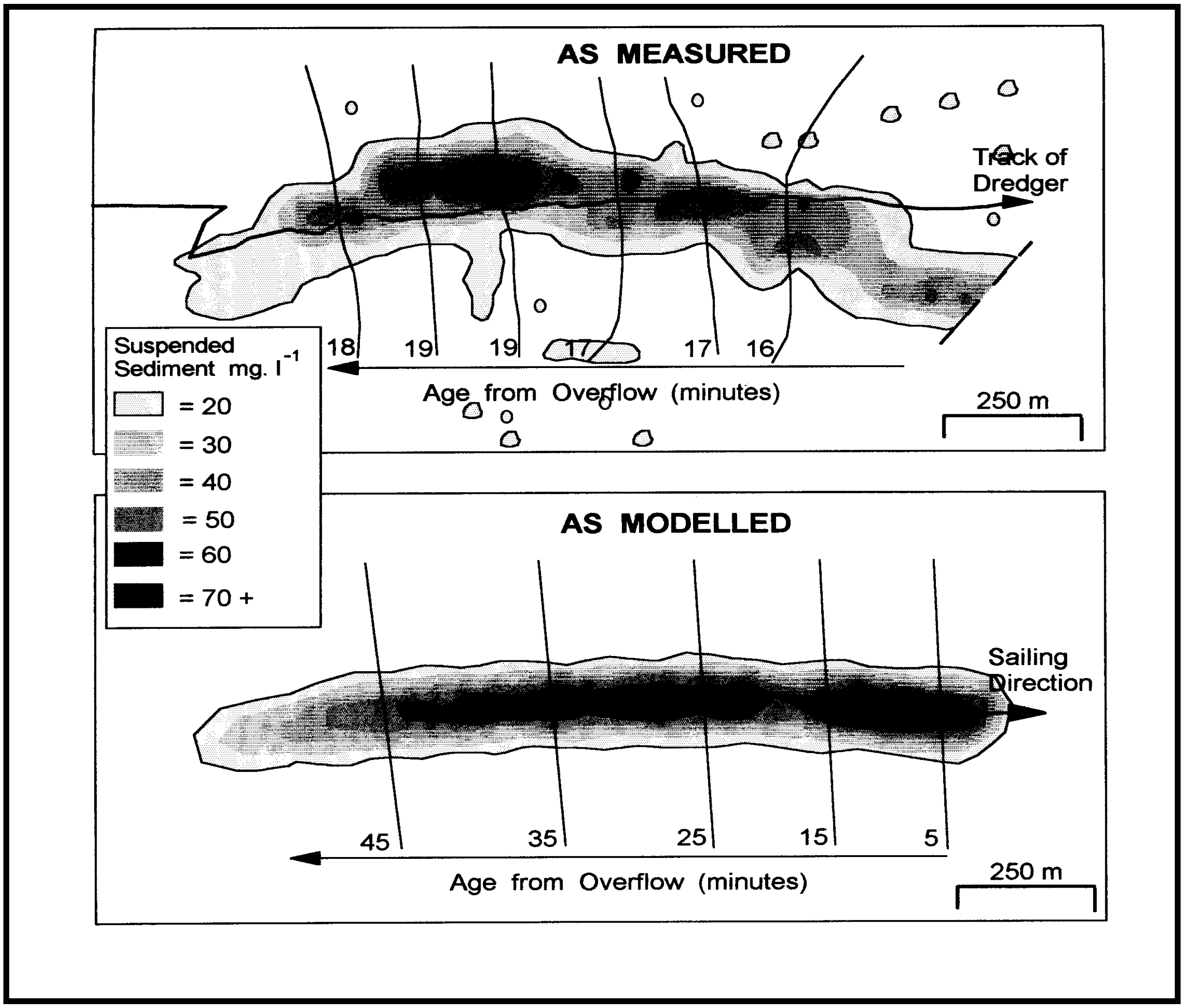

Figure 5.2b *Contours of suspended sediment concentrations astern of a trailer dredger operating in Hong Kong waters. Upper diagram shows contours as measured in the upper 8 metres of water across the plume at various time intervals up to 18 minutes after discharge. Lower diagram shows the output of a simulation model developed for sediment dispersion based on rapid sedimentation during an initial "Dynamic Phase" followed by a second longer "Passive Phase", which starts approximately 10 minutes after outflow (after Whiteside* et al, *1995)*

The turbidity plume caused by a combination of the draghead motions on the seabed and propeller screw disturbances were observed by Poopetch (1982). Fifteen minutes after dredging commenced, observations were also made of the plume developed due to hopper overspill. All plumes were observed to fully admix within 200m downstream of the vessel. Initial sediment concentrations in the surface seawaters adjacent to the overspill reached 3500mg/l, rapidly decreasing to 500mg/l within 50m downstream. Background levels of suspended solids concentrations were resumed at 150m laterally and within 800m longitudinally downstream.

Investigations in Hong Kong were undertaken at an early stage when marine dredging for aggregate was considered (Holmes, 1988). The concern for plume impingement on sensitive spawning grounds necessitated monitoring of water quality during dredging operations. The investigations concluded that within the water column the practical effects of enhanced suspended solids concentrations is difficult, if not impossible to assess. The effects were observed to be short lived and of limited areal extent and therefore concluded that suspended sediment impacts within the water column were negligible, away from spawning and mariculture zones. Interestingly, and probably related to the sampling methodology and dredging technique, SSC in the hopper surface waters was only 10000-30000 mg/l, reducing rapidly to 5000 mg/l adjacent to the dredger in the sea. A rapid dilution is therefore observed. Holmes (1988) observed that (1) the sand fraction settled quickly within a few hundred metres of the dredger (at a rate of 46mm/s for 320µm particles) and (2) the pelitic fines content will settle much slower at 0.1-1 mm/s and will therefore disperse over a wider area, observed up to 4km (Figure 5.2c).

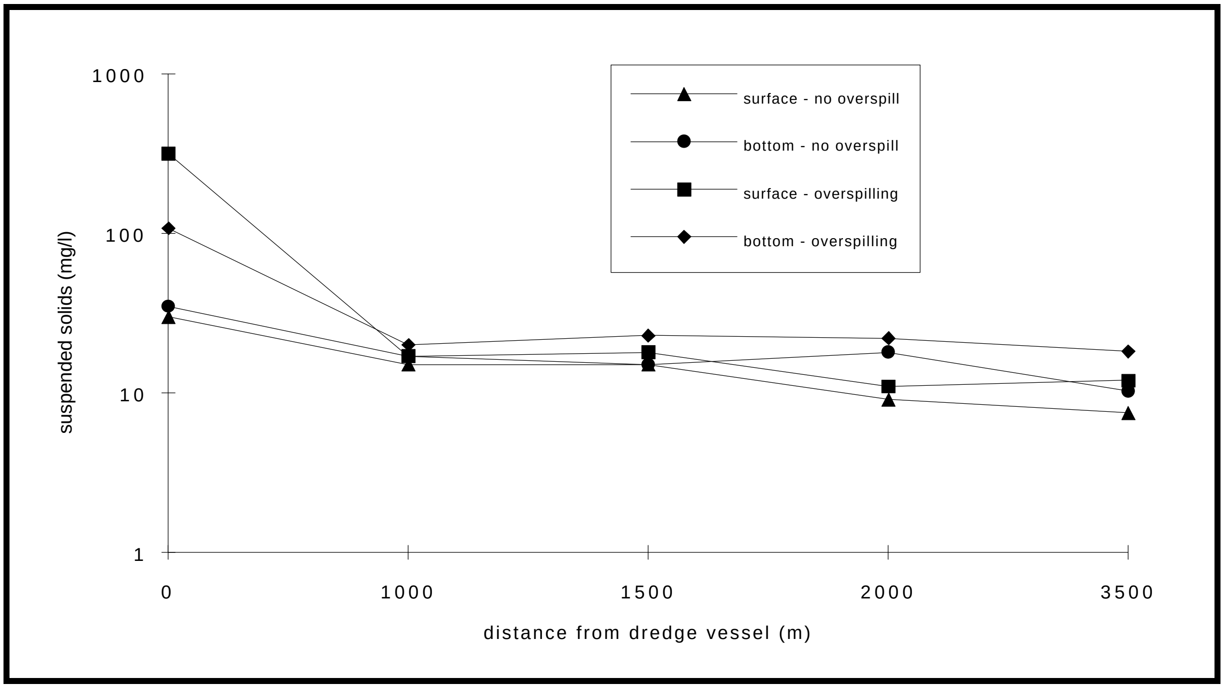

Figure 5.2c *Reduction in suspended solids concentration away from dredge vessel. Background concentrations away from site were 16mg/l (modified from Holmes, 1988)*

Kiørboe & Møhlenberg (1981) monitored the operation of a sand suction dredge in the Øresund, Denmark and concluded that any SSC likely to be detrimental were not present more than 150m downstream of the dredge. Levels adjacent to the dredge were up to 5000mg/l, rapidly decreasing to 100mg/l at 150m. Background levels were regained at 1000m downstream.

ICES (1986) report the detailed investigations that have been carried out in the Baie de Seine, France. During the course of the study, aspects of the overflowing sediments and there behaviour were observed. During the initial stages of the dredge loading operation, when the hopper is quite empty, particles in suspension in the overspill were all less than 315µm with some 15-20% less than 40µm. Later during the load, particle size increases to over 600µm. The fines content (<63µm) remained of the same order.

Using radioactive labelling of sediments, investigators also observed that the dispersion of the dredged material is limited in extent (ICES, 1977). An area of only 50 - 70 km^2 surrounding the dredge vessel exhibited increased turbidity. Particles less than 40µm were found to settle within 1500m of the dredge site.

Hayes *et al* (1984) reports on plume sampling whilst dredging silty clays in Grays Harbour, Washington, using a trailing suction hopper dredger. Observations indicated that the plume was largely dissipated (indistinct from background levels) and/or settled out within 300m of the dredger. It must be noted that the seabed disturbed and hence plume formed consisted only of fine grained silts and clays, and would therefore be expected to persist longer than those produced during aggregate dredging.

Willoughby & Crabb (1983) observed by aerial photography that the lateral dispersion of the plume rarely exceeded 200m with the plume-laden waters and clear water boundary clearly defined. Background SSC were observed as 3mg/l. Peak concentrations observed were at 0.5 hour old waters, having SSC of 20-25mg/l above background. After 2 hours, the SSC regained background concentrations of less than 3mg/l. The visible plume persisted for 8 hours overall.

Willoughby & Foster (1983) developed dispersion models to map the deposition rates of sediment following a two year period of intensive dredging on the Middle Banks, Queensland, Australia. A

200m wide corridor was predicted oriented downstream of the dredging area at 500m intervals. Table 5.2 below summarises the data predicted by their model.

Concentrations of suspended sand-sized material were reported to decay to background levels over a distance of only 200-500 metres from the point of release into the water column from a commercial aggregate dredger. Willoughby & Foster (1983) estimated that the sediment deposition 500-metres outside the boundary of the dredged area was 29.6kg.m^{-2} (23mm.m^{-2}). At 1-km deposition was 21.2kg.m^{-2} (16mm.m^{-2}), at 1.5-km it was 1 kg.m^{-2} (12mm.m^{-2}), at 2 km it was 10.7kg.m^{-2} (8mm.m^{-2}) and finally at 2.5-km from the boundaries of the dredged area the estimated deposition was less than 7.6kg.m^{-2} (6mm.m^{-2}).

Distance downstream from boundary of dredge area (m)	**Total Deposition after two years**	
	kg/m^2	mm/m^2
500	29.6	23
1000	21.1	16
1500	15.0	12
2000	10.7	8
2500	7.6	6

Table 5.2 *Estimated total deposition to south of Middle Banks, Australia, following two years of dredging activities removing 14 million cubic metres of sand from 5km^2 of seabed (from Willoughby & Foster, 1983)*

There is a good deal of evidence from other surveys that disturbance of sediments by dredging may release sufficient organic materials to enhance the species diversity and population density of organisms outside the immediate zone of deposition of particulate matter. Disturbance of the sediments may thus enhance benthic production outside the immediate zone of deposition provided that contaminants from polluted sediments are not associated with the disposal of spoils.

These studies confirm that the initial sedimentation of material discharged during outwash from dredgers does not, as had been widely assumed, disperse according to the Gaussian diffusion principles used in most simulation models, but behaves more like a density current (Land *et al*, 1994; Whiteside *et al* 1995; Hitchcock & Dearnaley 1995; *for review, also see* Pennekamp *et al* 1996) where particles are held together by cohesion during the initial phase of the sedimentation process. The principal area likely to be affected by sediment deposition is much less than the "worst case" scenarios predicted from conventional Gaussian diffusion simulation models, and is mainly confined to a zone of a few hundred metres from the discharge chutes. These recent results confirm earlier studies (*see*, *for example*, Poiner & Kennedy 1984; Willoughby & Foster 1983).

The results reviewed above thus suggest that the impact of dredging activities mainly relate to the physical removal of substrate and associated organisms from the seabed along the path of the drag head and to the impact of subsequent deposition of sediment from outwash during the dredging process. The evidence from direct studies on the sedimentation of particulate matter suggests that the impact of sedimentation on biological resources on the sea bed is likely to be confined to distances within a few hundred metres of the dredger where the deposits are sands and gravels.

It should be remembered, however, that discharge of dredge spoils from maintenance and capital dredging works in estuaries may result in much larger dispersion plumes which reflect the dominantly fine particles and strong sub-parallel current flows which occur in estuaries, and that the same processes which result in the release of dissolved organic matter can also result in the release of bound surface contaminants from the sediments into the water column.

5.3 Ongoing Research

Undoubtedly, further research into and monitoring of the generation and behaviour of plumes issuing from dredging operations is required. In the UK it is known that CEFAS (formerly MAFF) are undertaking further studies into the development of the benthic boundary layer excursion. Results are expected to be published shortly.

Additionally, DETR (formerly DoE) are funding research into improving the existing theory and methods for describing the magnitude and dispersion characteristics of the plume of fine material which is released during aggregate dredging (M Dearnaley *pers. comm.*). An important objective of this study is the establishment of appropriate settling velocities for the sediment fractions of the plume, which we have shown (by field monitoring) to be different to traditional, single particle behaviour. Using a purpose built settling column (Plate 5.3), observations of the settling velocity are determined through analysis of that fraction of the sample which has reached the base of the settling column after a known time. Results are due shortly.

Plate 5.3 *Measuring settling velocity aboard the ARCO Severn*

Section 7 outlines proposals for further research which requires addressing in the short to medium term (next 1-4 years). Of immediate importance, and which this project will continue to address through continuation of studies until May 1998, is firstly the acquisition of source term data for the reject chute, and secondly investigation of the biological content (5µm < Ø < 5mm) of the overspill and plume waters (Section 4.4).